Aquatic Macrophytes in Southern Amazonia, Brazil: Richness, Endemism, and Comparative Floristics

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Abstract

Southern Amazonia potentially harbors a wide diversity of aquatic macrophyte species because of its diverse wetland habitats and location in the Amazon-Cerrado transition zone, the two largest biogeographic domains in South America. We inventoried the taxonomic diversity of aquatic macrophytes in the region, including endemism, habitats, species life forms, and floristic comparisons with other Brazilian regions. We found a high number of species of aquatic macrophytes for the southern Amazon region, comparable to extensive inventories in larger areas in southern, northeastern, and northern regions of Brazil. We recorded 688 species of aquatic macrophytes in 299 genera and 95 families, of which 66 species are new records, 89 endemic, and 5 exclusive to Brazilian Amazonia. We present new records of aquatic macrophyte species, together with their degree of endemism and occurrence restricted to the region. The macrophyte species list of southern Amazonia showed 60% similarity to inventories in the Xingu basin and in northern Brazil. This high diversity of aquatic macrophytes in the Southern Amazonia, with endemic species and others with restricted ranges, emphasizes the importance of conserving wetlands and vegetation types where they grow in the region.

Introduction

Aquatic macrophytes grow actively while permanently or periodically submerged, floating, or emerging from the water surface (Chambers et al. 2008) and colonize most aquatic ecosystems to different degrees. The composition, richness, and cover of aquatic macrophytes may be determined by biotic factors such as climate, isolation, diversity of habitats, nutrients, and hydroperiod (Sousa et al. 2011; Schneider et al. 2019; Yang et al. 2020). The richness of aquatic macrophytes depends mainly on the size of a wetland, although their composition may not follow this pattern (Maltchik et al. 2007). Neotropical aquatic environments, with their generally high temperatures, water-level fluctuations, and wide variety of habitats harbor the highest richness and endemism of aquatic macrophytes (Murphy et al. 2003; Fortney et al. 2004; Murphy et al. 2019).

The Amazon Forest, the largest freshwater reserve in the world, supports one of the highest known levels of biological diversity, including over 50,000 terrestrial vascular plant species (Hubbell et al. 2009). The Amazon basin, situated between the Guianas Plateau to the north, the Central Plateau to the south, the Andes Mountains to the west, and the Atlantic Ocean to the east, drains, parts of eight South American countries in addition to Brazil (Hess et al. 2003). This phytogeographic domain covers an area of 6,500,000 km^2, with 60% or circa 4.2 million km^2 in Brazil, representing 49% of the country (IBGE 2010). Southern Amazonia extends widely (~6000 km), between latitudes 11°S and 14°S, and is an area of transition between the Amazon Rainforest and the Cerrado (Brazilian savanna). This ecotone region contains a diversity of habitats and vegetation types, from dense deciduous or evergreen forests to savanna formations (Marimon et al. 2006; Torello-Raventos et al. 2013). Within this environmental complexity, the Cerrado-Amazonia transition zone is rich in typical Amazonian tree species, also shared with the Atlantic Forest and the Cerrado (Marimon et al. 2006; Oliveira-Filho et al. 2017). The woody flora of this transitional region is well known, but the aquatic macrophyte flora is not.

Because of the heavy deforestation pressure for agricultural, timber, and hydroelectric development, this ecotonal region is known as the "Amazon deforestation arc". Deforestation may destroy immense genetic stocks that are little known or documented in herbaria or conserved in germplasm banks. Such genetic erosion can result in loss of valuable information, including information useful in areas such as agriculture, medicine, and industry (Fearnside 2019). Southern Amazonia may potentially harbor an enormous biodiversity of aquatic macrophytes because of its environmental heterogeneity (Murphy et al. 2019). The diverse wetland habitats include permanently or seasonally flooded areas such as streams, rivers, lakes, floodplains, marshes, and swamps, in addition to the reservoirs of several large hydroelectric power plants (Junk et al. 2020). The present study produced a checklist of aquatic macrophytes in southern Amazonia, in particular with information on new records, endemism, habitats, and life forms of the species, besides assessing the floristic similarity of the region to other areas within and outside the Amazon domain.

Methods

Study area

The state of Mato Grosso in central-western Brazil contains parts of three phytogeographic domains (Amazon, Cerrado, and Pantanal) and a diverse flora with high socio-economic and environmental potential. Vegetation types in the southern Amazon part of northern Mato Grosso include Transitional Forest, Evergreen Seasonal Forest, and Seasonal Forest of the southern Amazon border (Ivanauskas et al. 2004; Kunz et al. 2008). This part of southern Amazonia is an area of ecological tension (Veloso et al. 1991). The flux of biodiversity in the Cerrado-Amazonia transition and the complex mosaic of vegetation landscapes make it difficult to delimit the phytogeographic domains, especially in the transition zone (Marimon et al. 2006; Morandi et al. 2016a). The Amazon Forest covers approximately 500,000 km² in Mato Grosso, with areas of dense forest containing trees that can reach 50 m in height. The forest is cut through by large rivers and is protected in some preservation areas such as the Cristalino State Park, Rio Ronuro Ecological Station, and Xingu State Park. In the northern region, the Teles Pires and Juruena rivers join to form the large Tapajós River, and together with the Xingu River have a highly diverse flora along their banks (Fig. 1).

Collection of data

Survey of aquatic macrophyte species recorded in databases

To develop the species list for the part of southern Amazonia in mid-northern Mato Grosso, we included georeferenced records of herbaria in the region that are available in the *specieslink* (https://splink.cria.org.br) and Global Biodiversity Information system (GBIF – www.GBIF.org) databases. We checked all records individually and we added geographic coordinates of records with detailed information on the site location. Our selection of aquatic species followed the Repository of Aquatic Plants of Brazil (https://sites.icb.ufmg.br/plantasaquaticasbrasil) and the Brazilian Flora database (http://floradobrasil.jbrj.gov.br/), using the search filters "State: Mato Grosso", "Phytogeographic domain: Amazonia", "Substrate: Aquatic" and "Formation: Aquatic Vegetation". Based on reports from the state (Pott and Pott 1997) and the Amazon domain (Costa et al. 2016; Moura-Júnior et al. 2015), we included other species as aquatic macrophytes

Field collections

We also incorporated species collected by the authors during five years of field research (2015–2020) in the Tapajós (Teles Pires, Cristalino, Juruena) and Xingu (Xingu and Ronuro) sub-basins of the Amazon River, at different times and hydrological periods (drought, rising water, flood, and drawdown). Fertile specimens were recorded using random sampling, following the procedure described by Filgueiras et al. (1994). We identified the species by consulting literature, taxonomists, and herbarium collections. The specimens are kept in the Centro-Norte-Mato-Grossense Herbarium (CNMT) of the Acervo Biológico da Amazônia Meridional (ABAM) at the Universidade Federal de Mato Grosso (Sinop Campus), and establish several unique records for the state of Mato Grosso. We used the concept of aquatic macrophytes suggested by Cook (1996), including plants with photosynthetically active organs that are totally or partially submerged in fresh water or floating in aquatic habitats, either permanently or for several months of the year.

Floristic similarity, life forms, and habitats

We used geographical coordinates to circumscribe the records in the Amazon part of Mato Grosso with the help of the software Q-GIS (Q-Gis.org 2020), according to the delimitation of Brazilian phytogeographic domains (IBGE 2010), excluding records from other domains in the state (Cerrado and Pantanal). The habit description or the collection habitat was determinant for selecting records, which included only wetlands: riparian forests, lakes, ponds, rivers, streams, palm swamps (veredas), floodable grasslands, marshes, swamps, reservoirs, headwaters, *igapós* (seasonally flooded forests)*, and *igarapés* (small streams or channels). We obtained additional information on phytogeographic domains and growth habits from the Brazilian Flora database (http://floradobrasil.jbrj.gov.br/). The species list followed the classification of families proposed by the Angiosperm Phylogeny Group (APG IV 2016) for angiosperms, Smith et al. (2006) for ferns and lycophytes (pteridophytes), and Goffinet and Buck (2004) for bryophytes.

Classification of the species life forms of the aquatic macrophytes followed Irgang and Gastal (1996), based on the horizontal species zoning in the ecosystem and the water depth: amphibious, species that colonize the interface between aquatic and terrestrial habitats; epiphytes/climbers, plants rooted in organic substrates (emergent and/or floating); emergent, rooted plants with emerging leaves and flowers, occurring in shallow areas and close to the shore; and submerged and floating, species of deep and central zones and water bodies, occurring beneath or on the water surface, respectively. We obtained species life forms from our record collection and specific literature (Costa et al. 2016; Moura-Júnior et al. 2015; Pott and Pott 1997).

We categorized the habitat types as follows: lotic (rivers or streams), lentic (lakes and ponds), and intermediate, i.e., reservoirs or ecosystems with abiotic characteristics similar to lotic or lentic habitats (Thornton 1990; Esteves 2011). We categorized the habitats according to the information in herbarium records. The extinction risk of species was categorized using the IUCN database (International Union for Conservation of Nature, Red List of the Brazilian Flora) (http://cncflora.jbrj.gov.br/portal/pt-br/listavermelha). The categories are: Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Nearly Threatened (NT), Least Concern (LC), and Data Deficient (DD). We obtained other characteristics such as endemism and the phytogeographic domain (Amazon and/or Cerrado) of the species from the Brazilian Flora database (http://floradobrasil.jbrj.gov.br).

To obtain a general picture of the potential taxonomic richness in the region, we performed a rarefaction analysis of species to compare the observed (from the records) and the estimated richness (*Jackknife* 1 estimator), considering years as samples. We used the function *alpha.accum* of the *bat* package (R version 3.6.2, Cardoso et al. 2021). We analyzed the similarity between the southern Amazon aquatic macrophyte flora and those of eight other areas, including sites in other Brazilian phytogeographic domains (Table 1). We performed a cluster analysis (UPGMA) based on a presence/absence matrix, using the Simpson index (Magurran 2004). The analysis was conducted in the platform

R using the package *recluster*, function *recluster.cons*, and *recluster.boot* (R version 3.6.2, Dapporto et al. 2020). We updated all species names according to the Brazilian Flora database (http://floradobrasil.jbrj.gov.br), through the *flora* package (R version 3.6.2, Carvalho 2020).

Results

We cataloged 688 species of aquatic macrophytes (1 bryophyte, 29 ferns and lycophytes, and 658 angiosperms) in 299 genera (1 bryophyte, 19 ferns and lycophytes, and 279 angiosperms) and 95 families (1 bryophyte, 13 ferns and lycophytes, and 81 angiosperms). Of this total, 508 species (74%) were classified as aquatic macrophytes according to the Repository of Aquatic Plants of Brazil and the Brazilian Flora database, and 115 species (17%) were classified based on other surveys in the Amazon domain and other domains in Mato Grosso. For this study, we collected 308 species (45% of the total), of which 66 species (9%) were new records of aquatic macrophytes (Supplementary material; Fig. 2).

The families with the largest number of species were Poaceae (83 species), Cyperaceae (68), Fabaceae (56), Rubiaceae (41), Melastomataceae (27), and Onagraceae (23). These five families represent 43% of the entire aquatic species richness in southern Amazonia. However, 29% of the families have only a single species. The genera with the most species were *Cyperus* (29 species), *Ludwigia* (23), *Rhynchospora* (20), *Utricularia* (17), *Borreria* (14), and *Eleocharis* (14), all belonging to the five richest families, mainly Cyperaceae. Over half (59%) of the genera were represented by a single species (Supplementary material).

According to the Brazilian Flora database, 12% (79 species) did not have occurrence records for Mato Grosso and 15% (100 species) had not been recorded in the Amazon domain (Brazilian Flora database). Of the aquatic macrophytes recorded in this study, 13% (89 species belonging to 35 families) are endemic to Brazil, particularly the families Podostemaceae (11 species) and Fabaceae (9). We found 2 species in the Vulnerable category (*Mourera weddeliana* Tul. – Podostemaceae and *Ipomoea subrevoluta* Choisy, Convolvulaceae), 1 in Nearly Threatened (*Ottelia brasiliensis* (Planch.) Walp., Hydrocharitaceae), 47 in Least Concern, and 6 in Deficient Data (Table 2).

Regarding life forms, we found 399 amphibious species (58%), 170 emergent (19%), 14 rooted submerged (2%), 11 free submerged (1.6%), 20 rooted floating (2.3%), 7 free-floating (1%), and 68 epiphytes/climbers (9.4%). Considering the habitat of occurrence, the lentic species showed the highest richness, with 549 species, of which 241 were exclusive to lentic habitats; followed by lotic with 401 species (115 exclusive), and intermediate with 106 species (20 exclusives). Fifty-six species occur in all three habitat types.

According to the Brazilian Flora database, only 369 species of this group of plants have been recorded in the state of Mato Grosso. In the Amazon basin (southern Amazonia) in this state, the 330 species recorded is more than in other phytogeographic domains in the state, the Pantanal (254) and Cerrado (269). The same database lists only 453 species of aquatic macrophytes for the entire Brazilian Amazonia (Table 2).

The year-based rarefaction curve of species richness did not reach an asymptote (Fig. 3). Therefore, southern Amazonia may harbor an even larger number of species than we present here. Southern Amazonia showed low floristic similarity to other regions and phytogeographic domains. The highest similarity (60%) was to northern Brazil (Moura-Júnior et al. 2015) and the Xingu River (Abe et al. 2016) (Fig. 4). Southern Amazonia had low similarity to the flora of Virua National Park and *igapó* sites in northern and central Amazonia, respectively (Fig. 4).

Discussion

We found a high number of species of aquatic macrophytes (689) for the southern Amazon region, comparable to extensive inventories in larger areas in southern, northeastern, and northern regions of Brazil. We present new records of aquatic macrophyte species, together with their degree of endemism and occurrence restricted to the region. The Neotropical region is recognized for the high diversity of aquatic macrophytes, with 3457 species (Murphy et al. 2019), and its known richness continues to grow with new studies and records, chiefly in Amazonia and ecotones of vegetation types. The flora of this region shows a high degree of endemism, mainly in the northern part of the Amazon domain (Moura-Júnior et al. 2015; Murphy et al. 2019). The richness of aquatic macrophytes is related to several factors, with area size often noted (Ferreira et al. 2011; Murphy et al. 2003; Moura-Júnior et al. 2015; Moura-Júnior and Cotarelli 2019; Oliveira et al. 2019). Thus, the large area occupied by southern Amazonia (Amazonia of Mato Grosso), with 500,000 km^2 and a variety of wetlands containing rivers of the main Amazon basins, favors this high diversity of aquatic macrophytes. The bioclimatic conditions related to the low latitude of southern Amazonia, including the high temperature and humidity, variety of water-bodies, and plant cover lead to the high richness of aquatic macrophytes in this region (Murphy et al. 2019). Many studies have documented the increased richness of plant species in lower-latitude regions (Signor 1990; Cox and Moore 2006).

The high species richness recorded here may also be related to the location of the study area in southern Amazonia, in the Cerrado-Amazonia transition. This transition area tends to accumulate a high and often unique floral diversity (Marimon et al. 2006; Maracahipes-Santos et al. 2015; Marques et al. 2020). The meeting of the two largest biogeographic domains in South America, the Amazon and the Cerrado, provides a wide variety of habitats for the permanent or temporary occurrence of many aquatic macrophytes. Furthermore, the main rivers of southern Amazonia, the Juruena, Xingu, and Teles Pires, formed by the confluence of rivers that arise in the Cerrado, such as the Verde and Ronuro rivers,

may facilitate the distribution and colonization of species in the transition to the Amazon region. This transition zone harbors a high phylogenetic diversity of plants (Silva-Pereira et al. 2020).

The species richness found here exceeds that reported in similar studies, where the number of species did not exceed 300 (Pott and Pott 1997; Costa et al. 2016; Oliveira and Bove 2016). However, comparison among inventories must consider the criteria for inclusion, coverage area, and collecting effort. Nevertheless, this highest number of species records for northern Brazil (515 species) may be related to the larger extent and higher diversity of the areas sampled and the periods when the surveys were taken (Moura-Júnior et al. 2015). For northeastern and southern Brazil, long-term studies with sampling in widely distributed areas have reported high species richness (637 and 760 species, respectively) (Moura-Júnior and Cotarelli 2019; Oliveira et al. 2019). Most surveys in the Amazon region were done before 2016. However, we found the largest number of records between the years 2012 and 2019, derived from collections in aquatic-macrophyte monitoring programs for hydroelectric power plants (UHEs) in the study area, mainly in the Teles Pires River (UHEs Teles Pires, Colíder, and Sinop). Inclusion of this sampling effort in our study contributed to the increase of 343 species records for Amazonia, 29% of which are new occurrences for this phytogeographic domain. In addition, our inventory revealed four species (*Myriophyllum mattogrossensis* Hoehne, *Apinagia fluitans* P. Royen, *Lophogyne aripuanensis* (A.S. Tav.) C.T. Philbrick & C.P. Bove, and *Borreria flexuosa* E.L. Cabral) that occur only in Mato Grosso, and one, *L. aripuanensis*, that is exclusive to southern Amazonia.

The increase in species records for the region may also be due to failure to include many amphibious/emergent and epiphyte/climber species in the older lists. Labels from collections and herbarium records in *Specieslink* and GBIF do not adequately specify or describe the life form and/or habitat, hindering the characterization of species as aquatic macrophytes. We included many terrestrial plants that are tolerant of rapid inundation or running water in the sorting criteria. Correct recording of life forms is a key aspect in the study of aquatic macrophytes. We found many amphibious and emergent species, which results in a pattern similar to those found in other floristic studies of aquatic macrophytes, as mentioned above. The high number of amphibious and emergent species is attributable to habitat types such as riparian forests, where these species are frequent and often abundant in these temporarily flooded areas (Pott et al. 2011). The seasonality of other life forms, such as floating and submerged plants, may prevent them from being recorded in the field, since many appear in wetlands for only a short time; this is reflected in the lower number of species and survey records. Accuracy in determination and description of life forms often requires that studies be conducted for extended periods and over several hydrological cycles (Pivari et al. 2019).

The similarity of the macrophytes of southern Amazonia to the species recorded for northern areas of the Amazon domain was high, especially in the Xingu River region, mainly because of its proximity to the eastern boundary of southern Amazonia. Furthermore, the community of aquatic macrophytes showed differences within the Amazon domain, i.e., between central and southern Amazonia, as supported by the low similarity to inventories in the states of Roraima and Amazonas. This difference may be due to the influence of the Cerrado domain on southern Amazonia, as described for the tree flora of these regions by Morandi et al. (2016b). The low floristic similarity of southern Amazonia to the northern Amazon region (Viruá National Park), the Amazon igapó habitats, and the Araguaia River basin may have been influenced by the fewer species recorded in these situations, which although poorest in terms of species numbers, also possess a unique flora with few species shared with the other areas. Studies with greater temporal and spatial coverage in these areas are needed to explore their potential richness.

The richness of herbaceous aquatic macrophytes was determinant for the similarity between the study sites, particularly regarding families such as Poaceae and Cyperaceae. These families are the richest in wetlands worldwide (Murphy et al. 2019) and are very common in Brazilian wetlands, such as the Pantanal (Pott and Pott 1997) and the Paraná River basin (Murphy et al. 2003; Ferreira et al. 2011). The Lista de Espécies da Flora do Brasil (2020) includes 1653 species of Poaceae. Their efficient vegetative propagation (rhizomes and/or stolons) allows species of Cyperaceae and Poaceae to adapt to temporarily or permanently flooded areas, which explains their occurrence in all the habitats analyzed. The richness of Fabaceae in southern Amazonia coincides with studies of aquatic macrophytes in other Brazilian regions such as the Northeast (Moura-Júnior et al. 2019), North (Moura-Júnior et al. 2015), and South (Oliveira et al. 2019), where it is among the five richest families. Also notable is the relative importance of Onagraceae, which in most studies is not among the richest families despite its wide distribution in Brazil (Wagner et al. 2007). However, in our study it had the fifth highest species richness, with the genus *Ludwigia*.

The high species diversity in the region emphasizes the importance of conserving wetlands and vegetation types where they grow; many species have restricted habitats, as shown, for example, in the endemism levels. Conservation of the vegetation associated with watercourses is directly related to conservation of water resources, mainly in the Amazon region (Zaiatz et al. 2018; Lopes et al. 2020b). Despite this, over time, wetlands in Brazil have not received the economic, ecological and/ or social value that they deserve. On the contrary, many people favor transforming these areas for agriculture and cattle ranching, or for engineering projects such as hydroelectric power stations and roads (Junk et al. 2020), mainly in the so-called deforestation arc in southern Amazonia (Fearnside 2019). A frequent motive for transformation in the ruderal many aquatic macrophytes,which grow rapidly and can become invasiveand colonize impacted habitats (Barbieri and Carreiro 2017; Demarchi et al. 2018). This reinforces the importance of and need for maintenance and conservation of wetlands.

Floristic studies in wetlands in Brazil have continuously increased in sampling areas and number of species (Pivari et al. 2019). The present findings expand the available information on Amazon areas and habitats, and also increase the knowledge of species of aquatic macrophytes

that occur in transitional areas such as southern Amazonia. This new information will help to clarify the classification of these areas, which are often relicts of many communities and populations (Márquez et al. 2020). In summary, we recorded a large number of species, families, and life forms of aquatic macrophytes, with a high diversity, high degree of endemism, and several species with restricted occurrence in southern Amazonia, exceeding expectations and suggesting the desirability of further floristic studies in the region.

Declarations

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Tables

Table 1 Aquatic macrophytes floristics studies in Amazonia and other regions and Brazilian phytogeographic domains. MT: Mato Grosso state, MS: Mato Grosso do Sul, GO: Goiás, TO: Tocantins, RR: Roraima, PA: Pará, AM: Amazonas

Region (State)	Phytogeographic Domain	Species Number	Reference
Northeast (All States)	Caatinga, Atlantic Forest	637	Moura-Júnior and Cotarelli (2019)
Midwest (MT, MS)	Pantanal	242	Pott and Pott (1997)
South (All States)	Atlantic Forest, Pampas	780	Oliveira et al. (2019)
North (All States)	Amazon	539	Moura-Júnior et al. (2015)
Midwest, Araguaia river (MT, GO) North (TO)	Cerrado	162	Oliveira and Bove (2016)
North, Virua National Park (RR)	Amazon	207	Costa et al. (2016)
North, Xingu River (PA)	Amazon	295	Abe et al. (2015); Medeiros et al. (2015)
North, Igapós (AM)	Amazon	174	Lopes et al. (2020a)

Table 2 Number of species of aquatic macrophytes recorded in the Brazilian Flora database, per group, for the state of Mato Grosso and Brazilian Amazonia. MT: Mato Grosso and its phytogeographic domains: Ama-MT: Amazonia of Mato Grosso, Cer-MT: Cerrado of Mato Grosso, Pan-MT: Pantanal, and Ama-BR: Brazilian Amazonia, S-Ama: Southern Amazonia

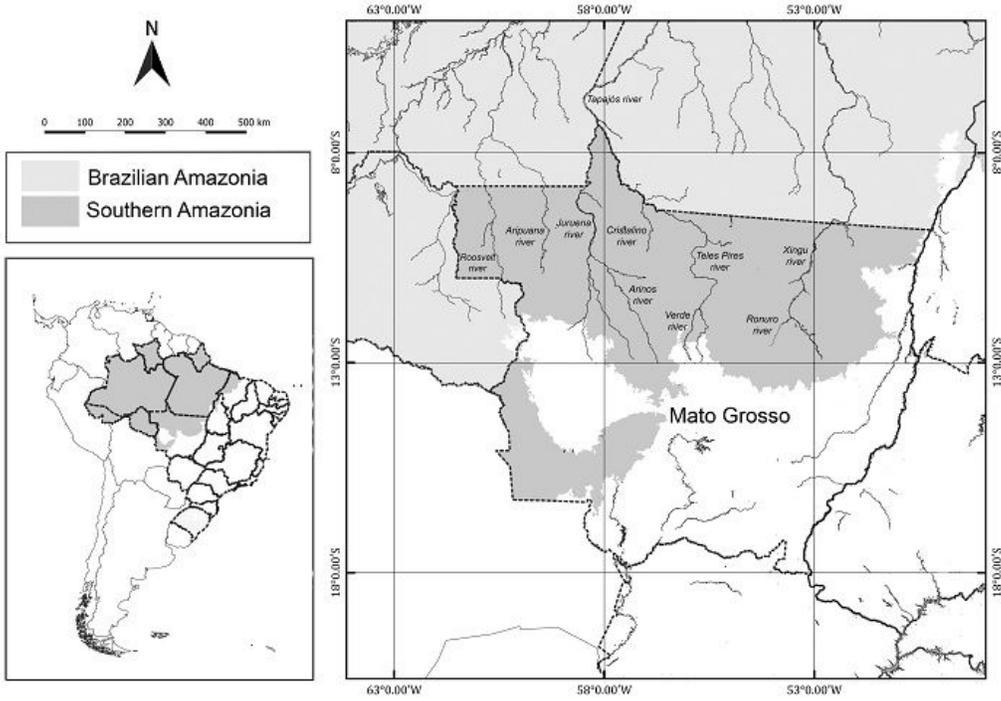|	MT	Ama-MT	Cer-MT	Pan-MT	Ama-BR	S-Ama
Angiosperms	353	321	258	245	420	658
Ferns and Lycophytes	10	6	5	5	16	39
Bryophytes	6	4	6	4	7	1
Total of species	369	330	269	254	453	689

Figures

Figure 1

Study area: the part of southern Amazonia located in the mid-northern and eastern areas of the state of Mato Grosso, Brazil Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 2

Examples of species of aquatic macrophytes of southern Amazonia. a. Helanthium bolivianum (Rusby) Lehtonen & Myllys, b. Limnocharis laforesti Duchass. ex Griseb., c. Erechtites hieracifolius (L.) Raf. ex DC., d. Varronia polycephala Lam., e. Ricciocarpos natans (L.) Corda, f. Cabomba furcata Schult. & Schult.f., g. Combretum lanceolatum Pohl ex Eichler, h. Palicourea amplectens (Benth.) Delprete & J.H. Kirkbr., i. Utricularia hydrocarpa Vahl., j. Schultesia guianensis (Aubl.) Malme, k. Ludwigia torulosa (Arn.) H. Hara, l. Utricularia breviscapa C. Wright ex Griseb., m. Desmoscelis villosa (Aubl.) Naudin, n. Aciotis acuminifolia (Mart. ex DC.) Triana, o. Echinodorus subalatus (Mart.) Griseb., p. Mayaca sellowiana Kunth, q. Chelonanthus alatus (Aubl.) Pulle, r. Hippobroma longiflora (L.) G. Don., s. Eleocharis minima Kunth, and t. Palhinhaea camporum (B. Øllg. & P.G. Windisch) Holub. Species in bold are newly recorded as aquatic macrophytes
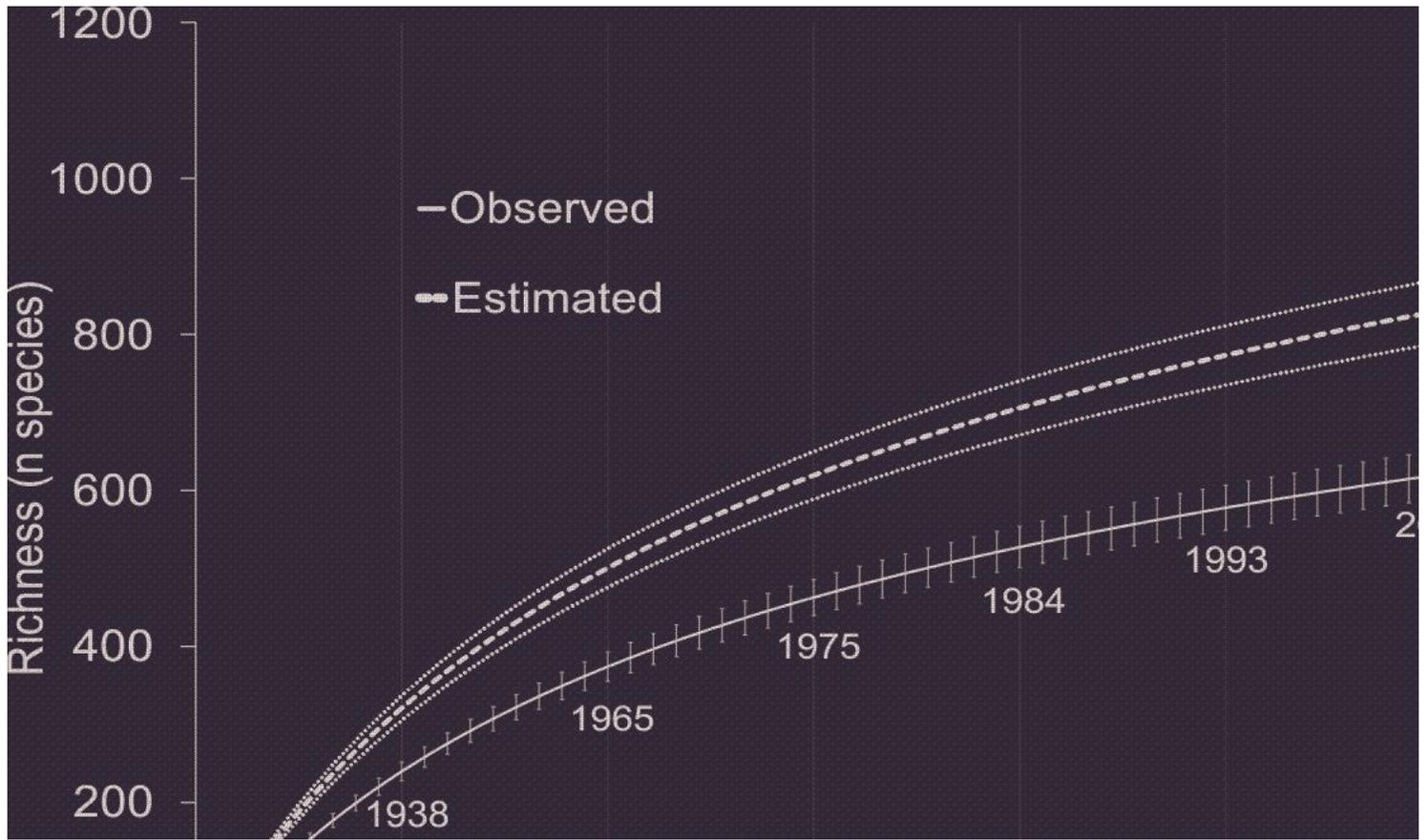
Figure 3

Year-based rarefaction curve for observed and estimated (Jackknife 1) species richness of aquatic macrophytes in southern Amazonia. Samples represent the species recorded in each year from 1903 to 2020
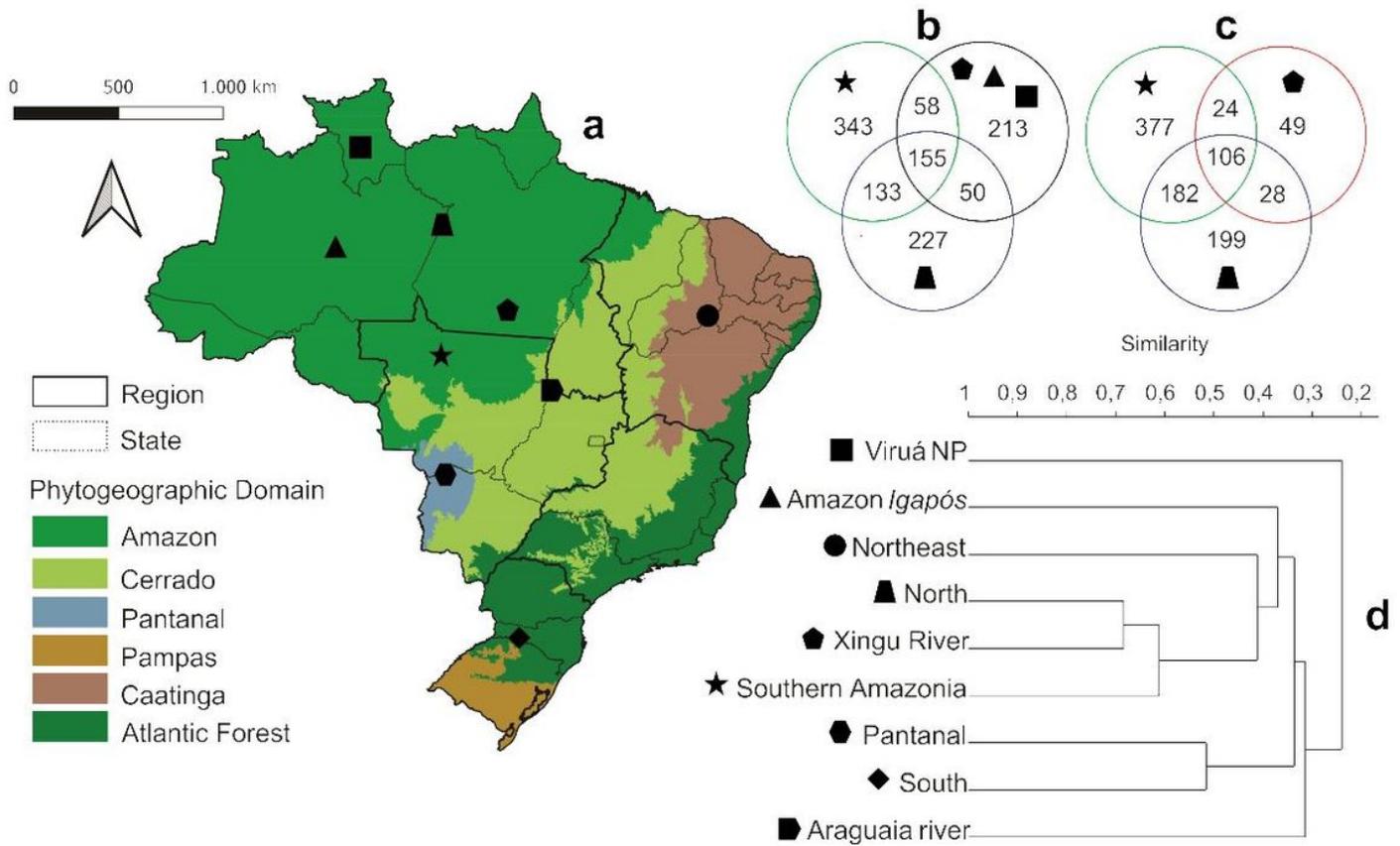
Figure 4

a. Map showing Brazilian phytogeographic domains and location of the study areas included in the analysis of floristic similarity of aquatic macrophytes. b. Aquatic macrophyte species of southern Amazonia shared with other areas of the Amazon domain. c. Species of southern Amazonia shared with the most similar group in the cluster. d. Cluster analysis dendrogram (UPGMA) based on the Simpson similarity index
Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

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